

- Trap as much sediment as possible in temporary or permanent sedimentation basins.
- Maintain completed works and assure frequent inspection for maintenance needs.

These principles can be implemented by a variety of simply constructed facilities. Detailed descriptions and design criteria are available in the literature [3]. Costs for some of the basic erosion control alternatives are presented in Table 63. Problem assessment and effectiveness analyses have been performed, in order-of-magnitude terms, using the Universal Soil Loss equation described in Section 5.

TABLE 63. EROSION CONTROL COSTS PER DEVELOPED ACRE [4]

Vegetative measures	Initial place- ment cost, \$/acre	First year maintenance cost, \$/acre
Seeding: seedbed preparation, seed and application, mulching at 2 tons/acre		
Temporary seeding by machine	240-330	50-120
Temporary seeding by hand	335-415	50-120
Permanent seeding by machine	790-1 220	50-120
Sodding, including seedbed preparation	2 400-3 600	240-2 900
Mulch, 2 tons/acre		
By hand	120-140	---
By machine	90-120	---
Mechanical measures		
Earth diversion berms	0.15-0.30	1.20-3.60
Straw bale barriers	0.75-1.10	1.20-3.60
Silt basins with earth dam, watershed area		
2 acres to 5 acres	600-1 200	500-750
25 acres to 100 acres	1 200-3 500	750-1 200
100 acres to 200 acres	3 500-5 000	1 200-1 800
\$/acre x 2.469 = \$/ha acre x 0.405 = ha tons/acre x 2240 = kg/ha		

MAINTENANCE AND OPERATION PRACTICES

The proper maintenance and cleanliness of the entire urban area can have a significant impact on the quantity of pollutants washed from an area by stormwater. Cleanliness of an urban area starts with control of litter, debris, deicing agents, and agricultural chemicals, such as pesticides and fertilizers. Regular street repair and sweeping can further minimize the pollutants picked up in stormwater runoff. The proper use and maintenance of

both catchbasins and the collection system can maximize control of pollutants by directing them to treatment or disposal.

Neighborhood Areas

Litter control--

Spent containers from food and drink, cigarettes, newspapers, sidewalk sweepings, lawn trimmings, and a multitude of other materials carelessly discarded become street litter. Unless this material is prevented from reaching the street or is removed by street cleaning equipment, it often is found in stormwater discharges. Enforcement of antilitter laws, convenient location of sidewalk waste disposal containers, and public education programs are just some of the source control measures. While difficult to measure, the benefits that occur are aesthetic improvement of the urban area and reduced pollution of the urban runoff.

According to a recent California study [5], in urban areas, litter accumulated at a rate of approximately 1.8 kg/person·yr (4 lb/person·yr). Of this total, about 0.84 kg/person·yr (1.8 lb/person·yr) appears as litter between the curb lines of streets in urban areas. It was reported that about 21% of the material picked up during mechanical street sweeping was litter.

Chemical Use Control--

One the the most often overlooked measures for reducing the pollution from stormwater runoff is the reduction in the indiscriminate use and disposal of toxic substances such as fertilizers, pesticides, oil, gasoline, and detergents.

Operations such as tree spraying, weed control, and fertilization of parks and parkways by municipal agencies, and the use of pesticides and fertilizers by individual homeowners can be controlled by increasing public awareness of the potential hazards to receiving waters, and providing instruction as to proper use and application. In many cases over-application is the major problem, where use in moderation would achieve equal results. The use of less toxic formulations is another alternative to minimize potential pollution. Comparative toxicities for several organic phosphorus and chlorinated hydrocarbon insecticides have been presented [6].

Pesticides have been detected in samples taken from several urban areas with typical loadings, including PCBs, between 40 and 3400 mg/curb·km (0.000136 to 0.012 lb/curb·mi) [7]. Direct dumping of chemicals, crankcase oil, and debris into catchbasins, inlets, and sewers is a significant problem that may only be addressed through educational programs, ordinances, and enforcement.

Street Sweeping--

Street sweeping is used by most cities to remove accumulated dust, dirt, and litter from street surfaces, but cleaning is usually done for aesthetic reasons. In many neighborhoods the amount of paper tolerated by the public governs cleaning frequencies [6]. Street cleaning practices have been shown

to be an effective method of attacking the source of stormwater-related pollution problems.

Street cleaning effectiveness is a function of (1) sweeper efficiency, (2) cleaning frequency, (3) number of passes, (4) equipment speed, (5) pavement conditions, (6) equipment type, and (7) public awareness [8, 9, 10].

Removal rates as reported in the literature vary considerably. In one study, the range was from 11 to 62% of the initial solids loading [11]. In another study, overall removal has been estimated at 33% of all pollutants on the street surface [9].

The relationship between concentration of pollutants found in urban stormwater and street sweeping frequency in one city is shown in Figure 21 [12]. The optimum interval can be determined by evaluating the trade-off of costs with effectiveness of sweeping.

Studies have also shown that the number of passes affects removal effectiveness [8, 7], as shown in Figure 22.

The effect of vehicle speed has been evaluated on residual debris. The optimum forward speed appears to be within the range of 5.6 to 8.0 km/h (3.5 to 5.0 mi/h) for efficient removal [7, 8].

The type of pavement affects both street cleaning efficiency and pollutant accumulation. While few data are available, in general, concrete pavements were found to be cleaner than asphalt streets. Pollutant loadings for asphalt surfaces have been estimated to be 7 to 20% higher than for other types of pavement [7].

The type of cleaning equipment also has an effect on the overall effectiveness of debris removal. Conventional sweepers are most efficient at removing larger contamination material, leaving behind the smaller fraction. Vacuum and air blast vehicles are capable of removing the smaller fractions. Vacuum equipment, however, rapidly loses its effectiveness when pavements are wet. This type of equipment has also experienced difficulties with clogged air hoses and filters due to clay-sized particles [6]. Water sprays can be used to remove street contaminants effectively; however, more frequent catchbasin and sewer cleaning may be required. The relative effectiveness of sweeping and flushing is shown in Figure 23.

Public awareness of, and participation in, street cleaning practices is essential for more efficient operations. Vehicles parked on streets during sweeping operations hamper efficiency and leave deposits untouched. Signs or flyers announcing sweeping schedules may result in more efficient operations [13]. One study [14] has concluded that 50% compliance with parking regulations yielded at best 25% of the curb swept. For 70 to 80% of the curb to be cleaned, the compliance with parking regulations must be maintained at 85% or higher.

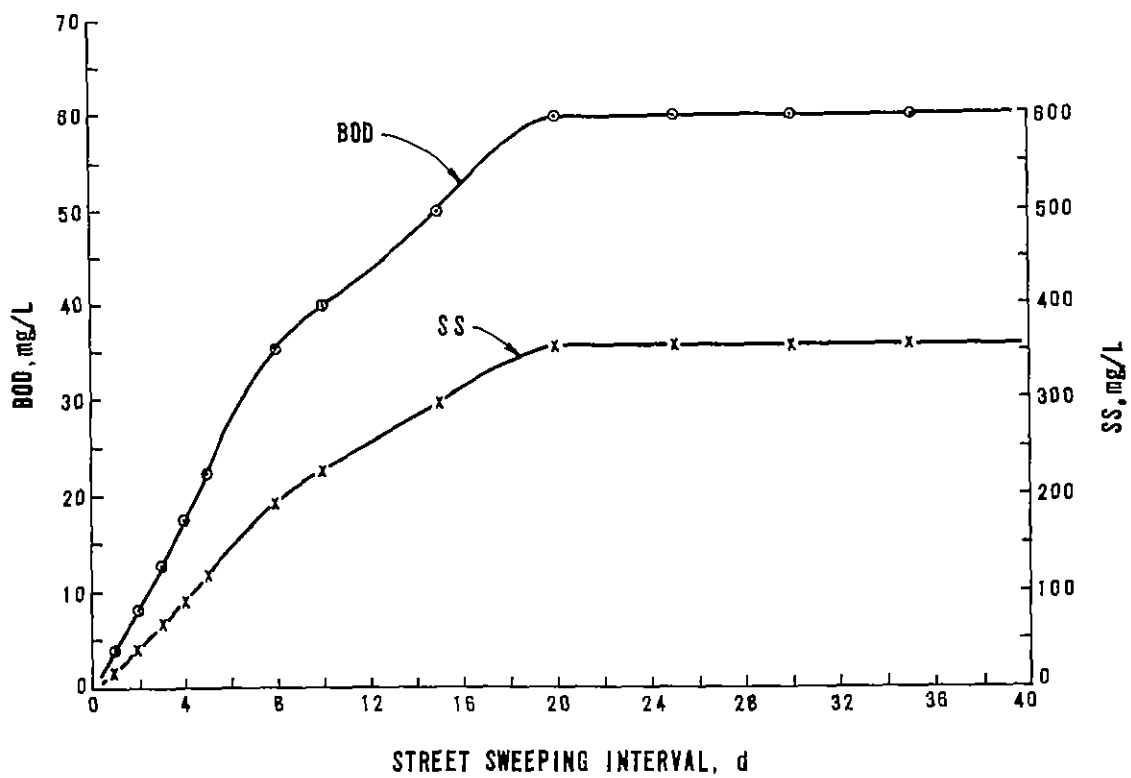


Figure 21. Effect of street sweeping frequency on mean BOD concentration in urban stormwater runoff, Des Moines, Iowa.

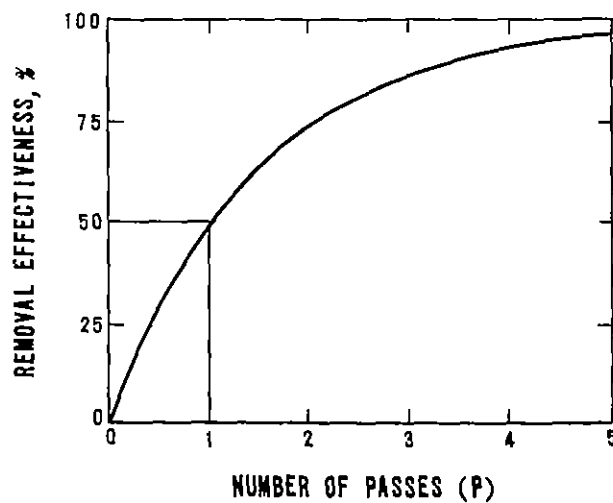


Figure 22. Street sweeping removal effectiveness with number of passes.

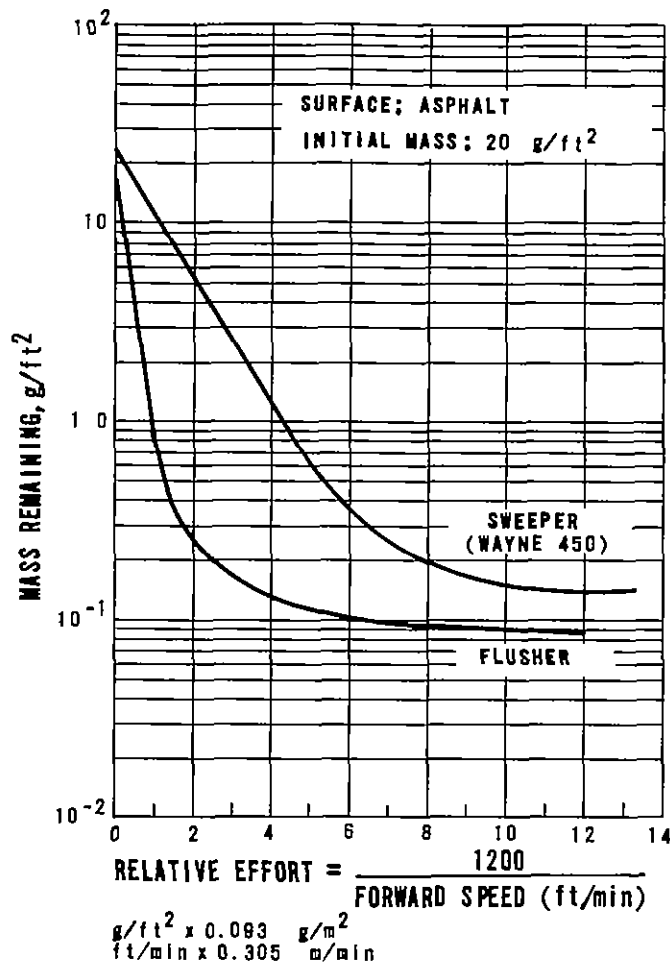


Figure 23. Comparison of cleaning performance of motorized street sweeping and motorized street flushing.

In terms of the reduced capabilities of the street sweeper as a result of illegal parking, if the assumption is made that a sweeper could remove 50% of the total solids, then 50% compliance would result in an overall efficiency of $(0.50 \times 0.25 \times 100 =)$ 12.5%. Eighty-five percent compliance would cause a 37.5% reduction in total solids. An additional problem is the removal of abandoned cars, which impede sweeper activities. In one section of Manhattan, cars were abandoned at the rate of approximately 150 per month. Although minor in comparison to the more frequent case of illegal parking, it still acts as an impediment to the technique.

Costs of street cleaning have been reported to range from \$1.97 to \$7.61/curb km (\$3.17 to \$12.24/curb mi) swept (ENR 2000). The wide variation in these costs was attributed to differences in labor rates, unionization, and equipment costs [7].

Street Maintenance--

Pavement conditions have been found to have an effect on the amount of pollutants found on the street [7]. A curve relating pavement condition and

solids loading for different land uses [9], is shown in Figure 24. In one report it was noted that as vehicles travel over rougher streets, more particulate matter is shaken off. A large portion of the solids also come from cracks in the pavement itself [13]. In terms of stormwater pollution, the optimum level of street maintenance could be determined by comparing costs of maintenance with the accumulation of pollutants.

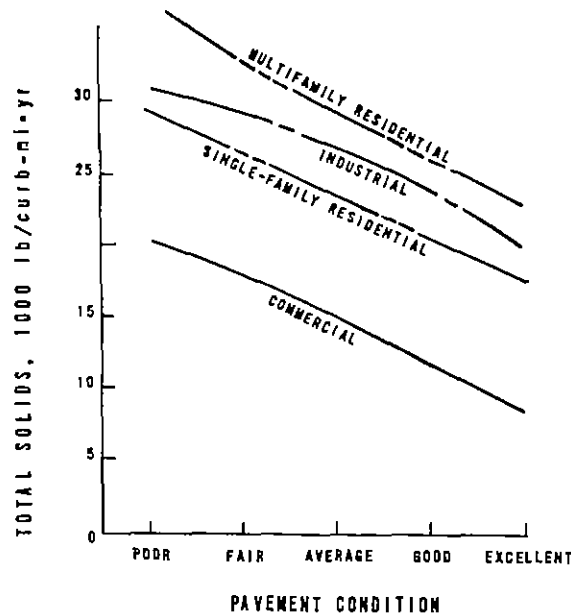


Figure 24. Effects of pavement condition and solids loading.

Management of Highway Deicing--

Effective management of highway deicing practices can lessen receiving water impacts associated with chlorides, sodium, and suspended solids, often without a substantial increase in costs.

Adverse environmental effects have been reported from the use of current deicing practices. Increases in chloride loads of 40 to 50% were experienced during the winter months, and chloride concentrations in the range of 1000 to 10 000 mg/L were found in receiving waters [15, 16, 17]. Sand contributes significant portions of suspended solids and causes maintenance problems with respect to catchbasins, and clogged storm and combined sewers [18]. Use of chemical additives such as cyanide, phosphate, and chromium can result in polluted snowmelt. Chromium concentrations of 3.9 mg/L have been reported [17].

- Recommended alternatives modifying current deicing practices include: (1) judicious application of salt and abrasives; (2) reduced application rates using sodium and calcium salt premixes: rates of 42 to 113 kg/lane km (150 to 400 lb/lane mi) have been recommended [19]; (3) using better spreading and metering equipment and calibrating application rates; (4) prohibiting use of chemical additives; (5) providing improved salt storage areas; and

(6) educating the public and operators about the effects of deicing technology and the best management practices [16-19].

Cost associated with salting of roadways, both direct and indirect, were estimated on an annual basis for the snowbelt states [20]. A total annual cost of \$3 billion was reported, of which only \$200 million was associated with salt purchase and application. Other costs in the total estimate included (1) water supplies and health, \$150 million; (2) vegetation, \$50 million; (3) highway structures, \$500 million; (4) corrosion damage, \$2 billion; and (5) utilities, \$10 million.

Collection System Maintenance

The major objective of maintenance of storm or combined sewer systems is to provide for maximum transmission of flows to treatment and disposal, while minimizing overflows, bypasses, and local flooding conditions. This objective can be achieved by maintaining the facilities within the system at their peak carrying capacity.

The significance of collection system maintenance as a best management practice is that when properly applied, extraneous solids and debris are removed in a controlled manner and thus do not accumulate as pollutant sources to be flushed into receiving waters under storm conditions.

The basic part of a maintenance program is regular inspection of the system. Specific tasks include: (1) catchbasin maintenance; (2) cleaning (both deposits and root infestations) and flushing of pipes; (3) removal of excess shrubbery, debris, and silt from flood control channels and ditches; and (4) control of inflow and infiltration sources.

Catchbasin Maintenance--

A catchbasin is defined as a chamber or well, usually built at the curblin of a street, for the admission of surface water to a sewer or subdrain, which includes at its base a sediment sump designed to retain grit and detritus below the point of overflow. The distinction is made between catchbasins as devices which intentionally trap sediment and storm inlets which do not have sumps and as a result should not retain sediment.

Historically, the role of catchbasins was to minimize sewer clogging by trapping coarse debris and to reduce odor emanations from low-velocity sewers by providing a water seal. With improvements in street surfacing and attention to design for self-cleaning velocity in sewers, their benefits were considered marginal as far back as 1900 [21]. Despite the purported reduced need, catchbasins are still widely used.

The area drained by a single basin is highly variable, averaging 0.63 ha (1.56 acres) in states with heavy snowfall and 0.88 ha (2.17 acres) in all states [22].

Catchbasins receive pollutants through the washoff of street surfaces and deliberate dumpings of crankcase drainings, leaves, grass clippings,

pet feces, etc. Survey results from samplings from several basins [18, 23] show a wide range of potential pollutant loadings in the retained liquid. For example, samples from 47 basins in San Francisco showed COD variations from 153 to 37 700 mg/L, a BOD range of 5 to 1500 mg/L, and total nitrogen, 0.5 to 18.2 mg/L. Normalizing the data by casting out the extremes and averaging, the characteristics reduce to: COD, 6400 mg/L· BOD, 110 mg/L· total nitrogen, 8 mg/L· and total phosphorus, less than 0.2 mg/L.

Using these averages, the approximate BOD₅ pollutant load held in a basin computes to 0.08 kg (0.18 lb), or the equivalent waste discharged by one person in one day. A rainfall intensity of 0.025 to 0.050 cm/h (0.01 to 0.02 in./h) lasting 4 hours is sufficient to displace 90% of the liquid contents of a catchbasin [24]. Thus, for a city the size of San Francisco, even a minor storm may discharge the wastewater equivalent of 25 000 people through the purging of catchbasins. If not intercepted, this is equivalent to reducing the net dry-weather plant effectiveness by 3% on the day of the storm.

Countering this negative impact is the removal of pollutants associated with the solids retained in the basin. Sartor and Boyd [7] have identified pollutants in street surface contaminants associated by particle size in the dry state. Using hydraulic modeling analyses (approximate model to prototype scale ratio of 1 to 3), Lager, Smith, and Tchobanoglous [25] have reported catchbasin removal efficiencies as a function of basin geometry, flowrate, influent solids gradation, and accumulated solids from prior events. From these data, preferred design criteria were recommended for new construction, as shown in Figure 25. The performance of the recommended basin under a graded simulant load is shown in Figure 26. The impact of accumulated sediment in the basin did not materially affect removal efficiencies until 50% of the sump had filled. Under further loads, the removals dropped rapidly. Negative efficiencies were experienced before 60% of the sump had filled. Total accumulations by particle size at the point of breakthrough are shown in Table 64. In the estimates of the BOD₅ pollutant load, it is assumed that 50% of the street contaminants remain with the solids and that the balance goes into solution.

If only half of the available street contaminants in an urban area reach a catchbasin in a typical storm, approximately 0.24 kg (0.53 lb) of BOD₅ could be retained [25]. This beneficial retention is approximately three times the adverse purged pollution computed above, provided that the basin is well designed and maintained.

Cleaning methods fall into four main categories: hand cleaning, bucket cleaning, eductor cleaning, and vacuum cleaning. Comparison of APWA survey data [22, 23] from 1959 and 1973 shows that, on a national basis, the median cleaning frequency has decreased from twice per year in the earlier survey to once per year at present. This trend is obviously detrimental from a water quality aspect and illustrates that many problems associated with catchbasins may be traced to inadequate maintenance.

In general, catchbasins should be used only where there is a solids transporting deficiency in the downstream collection sewers and drains or at specific sites where available surface solids are unusually abundant (such

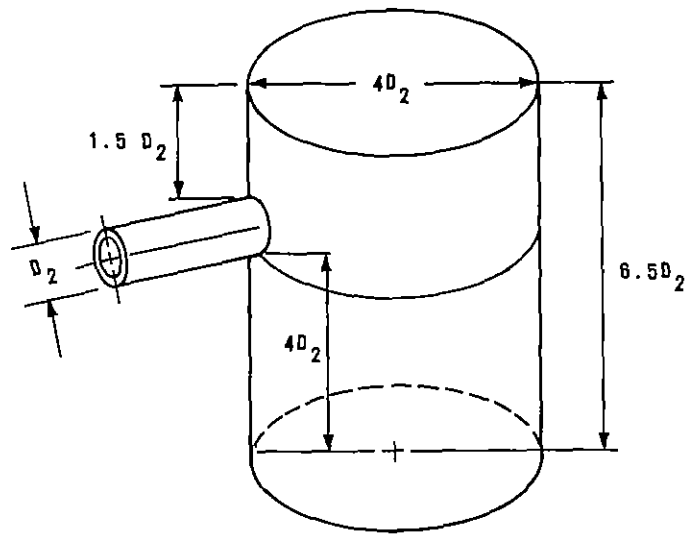


Figure 25. Recommended design.

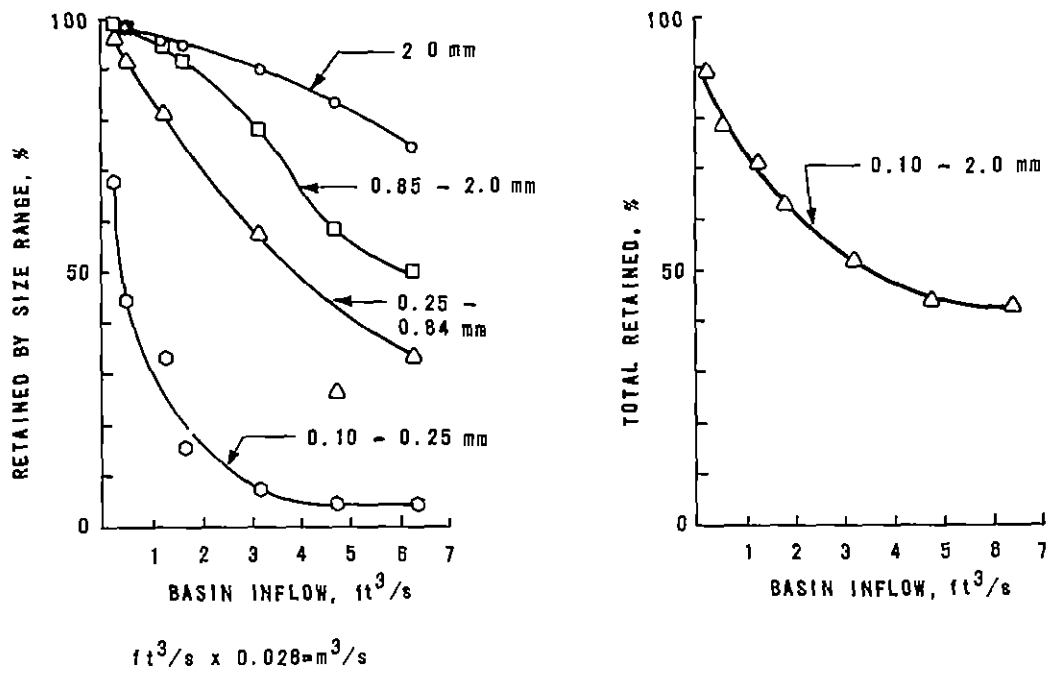


Figure 26. Solids removal efficiencies.

as beach areas, construction sites, unstable embankments, etc.). The advantages to be considered in the conversion of existing catchbasins to inlets are (1) a direct reduction in the "first flush" pollutant load, (2) a reduction in required maintenance, and (3) the opportunity to reallocate the conserved labor. Where catchbasins are required, the recommended cleaning frequency should be adjusted to limit the sediment buildup to 40 to 50% of the sump capacity [25], but in no case less than once per year.

TABLE 64. EXPERIMENTAL
EFFECTIVENESS OF CATCHBASINS

Particle size, mm	% of applied solids retained	Equivalent BOD ₅ removed, % ^a
0-10	0.0	0.0
0.10-0.25	10.0 ^b	3.3
0.26-0.84	47.8	7.6
0.85-2.0	75.4	3.8
2.0	<u>90.1</u>	<u>3.1</u>
Total	57.5	17.8

a. Percent of total level washed from streets

b. Estimated value

Sewer Cleaning and Flushing--

Sewer cleaning involves routine inspection of the sewer system. Any lines found to be plugged or restricted should be scheduled for cleaning and cleaned. The major causes of restrictions in large-diameter sewers are siltation and accumulation of large debris like shopping carts and tree branches. In small-diameter sewers, siltation and penetration of tree roots are the major problems. Beneficial aspects include reduced local flooding and reduced emergency-type repairs as well as pollutant loading reduction. Increased carrying capacities and reduced blockages in interceptor/regulator works may directly reduce overflows.

Many variations of sewer cleaning equipment have been used, covering a variety of hydraulic, mechanical, manual, and combination devices. The basic concept involved in cleaning of sewers is that a cleaning tool is pushed or pulled through the sewer to remove an obstruction or it causes the obstruction to be resuspended in the flow and carried out of the system. The cost of sewer cleaning is highly variable and dependent on the particular type of obstruction encountered as well as the physical configuration of the system. Experienced costs for cleaning small and medium diameter circular sewers are summarized in Table 65.

TABLE 65. CLEANING COSTS FOR
CIRCULAR SEWERS [26]

Pipe size, in.	Cost, \$/ft
6-10	0.30-1.30
12-18	0.35-2.25
21-24	0.70-4.25
30-36	1.15-6.80

in. x 2.54 = cm
\$/ft x 3.28 = \$/m

The cleaning of large sewers and interceptors involves some unique problems because sludge blankets several feet deep can accumulate. The removal of these sludges can be pursued in several ways. In Boston, manhole modifications to existing manholes were made to provide access to 3970 m (13 000 ft) of a 1.53 m (5 ft) diameter interceptor containing an estimated 3030 m³ (4000 yd³) of sludge. A 0.38 to 0.77 m³ (0.5 to 1 yd³) crescent-shaped bucket was used with winches to drag the sludge from the sewer. Removal of the sludge costs approximately \$46/m³ (\$35/yd³). The total cost of the project was estimated to be \$37.70/m (\$11.50/ft) of sewer [27].

Sewer Flushing-- Flushing of sewers on a regular basis can ensure the continuing capability of sewer laterals and interceptors to carry their design capacity as well as alleviate solids buildup reducing solids to overflow.

Sewer flushing can be particularly beneficial on sewers with very flat slopes (i.e., too flat for average flows to maintain sand and grit particles--with their associated contaminants--in suspension at all times). If a modestly large quantity of water is discharged through these flat sewers periodically, small accumulations of solids can be washed from the system. This cleaning technique is generally effective only on freshly deposited solids.

Internal automatic flushing devices have been developed for sewer systems. An inflatable bag is used to stop flow in upstream reaches until a volume capable of generating a flushing wave is accumulated. When the correct volume is reached, the bag is deflated with the assistance of a vacuum pump releasing impounded water and cleaning the segment of sewer [28].

The flushing wave will be attenuated by wall friction and other internal pipe irregularities and has limited usefulness. It is estimated that approximately 370 m (1200 ft) of small and medium diameter sewer could be flushed by a single flushing station.

For 46 to 61 cm (18 to 24 in.) pipes, an automatic flushing station capable of being installed in an existing manhole would cost approximately \$6000. This station would require routine inspection (once a month). It would have an estimated annual operating cost of \$500 and would consume approximately \$50 worth of power annually.

Drainage Channel Maintenance-- Maintenance of flood control channels can cover a wide range of cleaning tasks. Debris to be removed ranges from trash, garbage, and yard trimmings to used tires and shopping carts. Currently, very little cost data are available on the maintenance of flood control channels. A limited survey of West Coast flood control districts indicates that the cost for maintenance of flood control facilities range from \$2.50 to \$5.75/linear m (\$0.75 to \$1.75/linear ft) of facility. This cost would be affected by the size of channel, the type of channel lining, and the access to the channel. Other facility maintenance costs are shown in Table 66.

TABLE 66. OPERATION AND MAINTENANCE COSTS
FOR FLOOD CONTROL FACILITIES

Item	Factor-yearly cost
Concrete structures	0.1% of first cost
Gates and steel structures	1.5% of first cost
Levees	\$960 + \$16/ft height·m
Riprap slopes	\$70/ft height·m
Unlined slopes	\$144/ft height·m
Channel	\$320/m
Roads and berms	\$400/m
Interior drainage facilities	2% of first cost
Undeveloped riverbanks	150% of developed bank cost

$$\begin{aligned} \$/\text{ft height} \cdot \text{m} \times 2.038 &= \$/\text{m height} \cdot \text{km} \\ \$/\text{m} \times 0.622 &= \$/\text{km} \end{aligned}$$

Inflow and Infiltration--

The entering of extraneous flows into a sewer can be generally categorized as either inflow or infiltration. Inflow usually occurs from surface runoff via roof connections, cross connections between sanitary and storm sewers; yard drains, or flooding of manhole covers. Infiltration usually occurs by water seeping into the pipe or manholes from leaky joints, crushed or collapsed pipe segments, leaky lateral connections, or other pipe failures. By reducing effective collection system and treatment plant capacities, extraneous flows may result in unnecessary pollution.

The location and assessment of inflow-infiltration sources have been discussed at length in recent literature [26, 29]. The cost for an evaluation survey to determine the magnitude of inflow/infiltration ranges from \$3.60 to \$7.70/m (\$1.10 to \$2.35/ft) of sewer (1974 dollars).

Some of the most common sources of inflow are summarized in Table 67. Estimates are given for the flow contributed from each source and the cost of eliminating that source are also given.

TABLE 67. REHABILITATION COST ESTIMATES
FOR INFLOW ELIMINATION

Inflow source	Flowrate, gal/min	Rehabilitation cost (ENR 2000), \$
Leakage around manhole covers	10-20	50-75
Holes in man- hole covers	50-100	100-125
Foundation drains	10	300-1200
Roof leaders	10	50-75
Cross connection	250-450	100-500
Catchbasin	300	3000-5000
Ditch or storm sewer-- infiltration sanitary sewer (per manhole reach)	60-80	500-2500
Area drains	50-200	50-350

gal/min x 0.0631 = L/s

Infiltration is usually more difficult to locate, and more expensive to cure. The worst possible case would require replacement of a segment of sewer between two manholes (commonly called a reach). If only minor infiltration exists, a small-diameter sewer can be grouted using pressurized pumped sealants. Typically, grouting a manhole reach with up to three infiltration sources costs approximately \$600. Detailed costs for the control of inflow/infiltration sources are presented in recent literature [26].

Onsite Storage of Runoff

The objective of onsite storage of runoff is either to prevent storm flow from reaching the drainage system or to change the timing of the runoff by controlling the release rate. Retention is the term for total containment, and detention is the common term for delaying and controlling the release rate to smooth out the peak flows.

Use of onsite storage allows a natural drainage system or a less extensive, less costly manmade system to be used.

Pollution Control--

The ways in which stormwater pollution is reduced by onsite storage are as follows:

- There is no surface water pollution loading from retention facilities. (However, the effect of infiltrating water on groundwater should be analyzed.)

- Delaying runoff and stretching out the pollutant loading over a period of time enhances the ability of the stream to assimilate pollutants.
- Planned onsite storage can be used to keep rainwater from running off urban surfaces that are potential sources of pollution, such as urban streets.
- The decreased velocity of storm runoff caused by detaining peak flows will result in less channel erosion in natural streams and earthen conduits. The lower velocities also mitigate the impact on organisms living in the stream.
- If peak flowrates of stormwater through combined sewers can be controlled, the overflows of heavily polluted combined sewage can be decreased or eliminated.
- Detention of stormwater in a pond for any period of time will result in some settling and thus may decrease the particulate loading of the outlet water. Some biological stabilization may also occur.

The precipitation/infiltration process is the most important method of replenishing the groundwater reservoirs that serve as potable water supplies for many areas of the country. The decreased infiltration and increased water demand caused by urbanization will stress groundwater supplies unless recharge areas are set aside as basins develop. Although large-scale urban stormwater recharge programs have not been implemented because of potential groundwater pollution, onsite retention and recharge has been developed for small watersheds. Retention basins are usually variable-depth ponds designed with no outlet or only a bypass for exceptionally high flow conditions.

Retention is also practiced as controlled onsite storage where groundwater recharge is not important. In a typical example, the California Division of Highways has built retention basins to dispose of highway runoff in the San Joaquin Valley. These basins were developed from 0.4 to 2.4 ha (1 to 6 acre) depressions that had originally been excavated for embankment material. Infiltration capacity is sometimes improved by excavating 1.8 to 3.1 m (6 to 10 ft) deep trenches or vertical drains and backfilling with porous material. Maintenance is minimized by providing low-velocity channels ahead of the basins to help settle suspended particles. The areas are scarified once a year to decrease the surface clogging effects of organic solids.

The alternative to retention is to construct sewers to carry the runoff to acceptable receiving waters. Therefore, the economic advantages depend on the length of sewer that would be required. Additional advantages of the ponds include total containment of the highway runoff pollutants and the recreational asset to local cities that can landscape the basins as additional parkland.

Detention-- In its simplest form, detention means capturing stormwater and controlling the release rate to decrease downstream peak flowrates. Onsite detention uses simple ponding techniques on open areas where stormwater can be

accumulated without damage or interference with essential activities. The design essentials include a contained area that allows the stormwater to pond and a release structure to control the rate at which the runoff is allowed into the drainage system. The release structure is usually a simple construction, such as a small-diameter pipe draining a basin or an orifice plate placed at a sewer inlet. The capacity of the pipe or orifice limits the flowrate to a level acceptable to the downstream system. Where the depth of ponding has to be limited, the release structure will have an automatic overflow to prevent excessive ponding.

Surface ponding is the most common form of detention being used by developers. In most cases the facilities are carefully planned so that the ponding area is a dual-use facility that enhances the value of the site. Variable level ponds have a permanent water level during dry weather and increased holding capacity during storm conditions. The permanent lakes have aesthetic and recreational appeal which increases lot values. Basins that are dry between storms are often designed to be used as baseball fields, tennis courts, and general open space. Parking lots can be made to serve as low-depth storage ponds by sloping the sides and constructing drain outlets. Side slopes are restricted to about 4 percent for traction in the winter, and the pond depth is limited by the need for people to reach their vehicles. Obviously, a truck terminal lot can be allowed to pond to a greater depth than a supermarket lot. The economic aspect of surface ponding is derived from the savings over a conventional sewer project. Several surface ponding sites are listed in Table 68. A cost comparison is also made between a drainage system using surface ponds to decrease peak flows and conventional storm sewer construction. Greater benefits are obtained if the pollution control aspect is considered.

TABLE 68. SURFACE PONDING [30]

Site	Description	Cost estimate, \$	
		With surface ponding	Without surface ponding
Earth City, Missouri	A planned community including permanent recreational lakes with additional capacity for storm flow	2 000 000	5 000 000
Consolidated Freightways, St. Louis, Missouri	A trucking terminal using its parking lot to detain storm flows	115 000	150 000
Ft. Campbell, Kentucky	A military installation using ponds to decrease the required drainage pipe sizes	2 000 000	3 370 000
Indian Lakes Estates, Bloomington, Illinois	A residential development using ponds and an existing small diameter drain	200 000	600 000

Two variations of detention that have proven successful for metropolitan application are ponding on plaza areas and ponding on roof tops. Both techniques have been pioneered at the Skyline Urban Renewal Project in Denver, Colorado [31]. The basic approach is the same for other forms of detention. The outlet from the ponding area must be constructed to allow runoff to accumulate during peak storm conditions. The depth that can accumulate on plazas must be limited to approximately 1.9 cm (0.75 in.) because of pedestrians, but it is possible to design plazas so that portions can be flooded without inconvenience. A depressed plaza section in Denver is shown in Figure 27. Roof tops in metropolitan areas provide an excellent opportunity for stormwater detention. Most are flat, watertight, and structurally designed to take loads greater than that of ponded stormwater. It adds very little to the cost of a new building to ensure structural conditions for ponding. Detention is controlled by a simple drain ring set around the roof drains. As the roof begins to pond, flow is controlled by orifices in the ring; extreme flows overflow the ring to prevent structural damage to the roof.



Figure 27. Depressed plaza ponding, Denver, Colorado.

Design Considerations--

The acceptability of onsite storage as a pollution control alternative depends on the mitigation of apparent adverse factors, including the safety hazard to children, maintenance difficulties, mosquito breeding, algae growth, the land area required, possible poor appearance of dry ponds, and the responsibilities of ownership.

Safety-- The safety features depend on the secondary use of the facility. Obviously, a dual-purpose recreational lake cannot be fenced to prevent

access. Typical safety features include shallow bank slopes and outlet guards.

Maintenance-- Debris removal, care for the landscaping, and maintenance of the outlet structure are all part of the routine operation of a detention facility.

Mosquito breeding and algae growth-- Both mosquito and algae problems can be eliminated from dry basins by ensuring that the areas dry out completely between uses. For permanent ponds, these problems are more difficult to control. Mosquito breeding can be upset by controlling grass at the shoreline, varying the water depth every few days, or stocking the ponds with larvae-eating fish.

Land area required-- The best way to overcome objections to land set aside as a detention pond is to recognize that the area can be an asset as open space. Housing near greenbelts and pond areas usually has a higher market value if the open space is aesthetically designed.

Poor appearance of dry ponds-- Detention ponds are most presentable when a grass cover is kept on the basin slopes and floor. Grasses can be grown that will withstand periodic flooding. If retention basins contain water for long periods of time or need to be vegetation-free for better infiltration, appearance objections may be overcome by sight barriers such as trees.

Responsibility of ownership-- In most cases the responsibilities of operation and ownership should be assumed by a public agency. The equipment, manpower, and expertise required for operation and maintenance is beyond the abilities of homeowner associations and developers.

LEGISLATION

Special legislation is necessary to implement many best management practices effectively. Laws, ordinances, and agreements will simplify the process of draining upland areas with a minimum of flood damage and pollution. The alternative, civil suits and tort law, becomes almost unworkable when thousands of property owners are involved. The simplest form of legislation, and the form enacted in most urban areas, provides for a public works authority to build and maintain a drainage system to transport runoff to a major receiving water stream. The authority is funded or empowered to raise money and allowed to acquire property or easements for the system.

In most cases, the flood control or drainage authority succeeds in meeting its primary objective, quick removal of stormwater, by channeling runoff into large concrete conduits and discharging at a point downstream from the newly urbanized area. Some major difficulties can develop from the implementation of the typical runoff system.

1. The combination of a generally impervious urban area and a system designed to remove runoff as quickly as possible will increase flood peaks in the receiving stream. This increase may be disastrous for downstream residents.

2. Urban runoff has the pollutorial characteristics of a weak sanitary sewage and consequently there is a growing realization that some type of treatment should be required before discharge into sensitive receiving waters. Since many collection and treatment components are necessarily sized on the basis of the peak rate of flow, it would be cost effective to decrease both runoff peaks and volumes.
3. The common growth pattern for an urban area consists of an older city on the banks of a receiving stream with suburban areas developing on the perimeter of the city. These newer suburban towns must often drain through the original city to the stream. Aside from jurisdictional problems, the increased flow will tax the capacity of the city's system in highly developed areas where construction to increase capacity is difficult and expensive.

One solution to these problems is drainage basin legislation requiring that hydrologic changes be kept at a minimum during development. If the rainfall and runoff pollutants are contained at the source, the downstream problems are mitigated. Legislation to accomplish the containment is more complex and controversial than common drainage laws. At a minimum it will require that a percentage of the land be left undeveloped and dedicated to infiltration or detention basins. The legislation may be very controversial if it severely restricts the ways in which private land can be developed.

General Concepts

The development of a runoff policy requires that a legislative authority representing the drainage basin (usually a county or state) study the problems of the basin, formulate objectives, and outline methodology for meeting the objectives. The actual engineering involved in detailing the methodology is usually developed in a manual of regulations by the public works authority designated to enact or enforce the legislation.

The problems that must be defined will vary by basin and receiving water but generally fall into the categories of flood protection, pollution abatement, erosion control, and groundwater protection. The objectives of the legislation will include some of the following points:

- To protect the public health, safety, and welfare
- To define responsibility for all aspects of the problem, i.e., will solutions be developed by cities, developers, or private landowners?
- To authorize administrative and/or public works departments to implement the legislation
- To implement the most equitable and cost-effective solution to the problem
- To protect the receiving water
- To conserve stormwater for beneficial use

- To control development in the flood plain
- To provide a basis for future development by considering areas where growth should be controlled or encouraged

The objectives have to deal with future conditions as well as the present and in fact legislation is more successful in preventing future problems than in solving existing ones.

The basic methodology is the containment of all or part of the runoff and pollutants at or near the source. The options for accomplishing this will be illustrated by examples of programs in several areas. The choices may include:

- Regulations requiring that the rate or volume of runoff after development be the same as predevelopment levels
- A program by a municipal authority to build upstream detention or retention facilities
- Regulations prohibiting construction in natural ponding areas or floodways
- A system for runoff control taxes that are prorated according to the amount of runoff generated from the property
- Erosion and sediment control ordinances designed to prevent soil loss, especially during construction activities
- Anti-littering and discharge ordinances that prohibit the use of channels and stormwater systems to dispose of refuse, motor oil, and other foreign material

The methodology should be presented in the legislation to give a clear mandate to the implementing authority. However, it is not necessary to give specific design regulations for engineering solutions required. For example, it is preferable to require that runoff not exceed historic rates for the 10 year storm rather than mandate a certain size retention basin. The former case will allow the landowner or municipality to develop the best engineering solution for the individual site.

The legislation can take any of several forms depending on the authority and objectives of the legislative body. Examples would include municipal ordinances, flood control ordinances, building codes, zoning plans, subdivision regulations, sewer and drainage fee assessments, greenway or open space plans, and pollution control ordinances.

Example Programs

A summary of ten innovative programs as reported in the literature [30, 32] is presented in Table 69.

TABLE 69. SUMMARY OF LEGISLATIVE
STORMWATER MANAGEMENT PROGRAMS

Location	Description of legislation
Denver Urban Renewal Authority	Requires private developers to pond rainfall on rooftops and in plazas of all new and renovated construction. The design criteria for plazas require a runoff rate of 1 in./hr and a water depth of 0.75 in. during the 10 year rain. The values for rooftops are 0.5 in./hr and a depth of 1 in. for the 10 year storm or 3 in. during a 100 year rain.
Naperville, Illinois	Plumbing, sewer, and water ordinance requiring that runoff release rate be regulated by the safe capacity of the receiving water, but no more than 0.15 in./h. Storage must be designed for the 100 year storm. The ordinance is applicable to all new subdivisions and compliance is required for approval of development permits.
Joliet, Illinois	Ordinance similar to that of Naperville. Requires runoff to meet a variety of criteria: (1) runoff rate shall not exceed historic values, (2) allowable runoff rates are prorated on the basis of stream capacity, and (3) runoff rate shall not exceed that of 2 year storm with a runoff coefficient of 0.3 unless facilities can handle the flow. The ordinance is enforced for 10 acre residential areas and 5 acre nonresidential developments through the issuance of building permits.
Albuquerque Metropolitan Arroyo Flood Control Authority	Requires stormwater detention for all new developments such that downstream drainage facility capacity is not exceeded or the rate of runoff does not exceed the natural rate of flow. Compliance is required for building permits and subdivision plat approval. In addition, a land use not in compliance can be sued as a public nuisance.
Arvada, Colorado	Requires detention for runoff greater than predevelopment rates for new construction. If a developer chooses not to provide the detention he is assessed a one time fee that reflects the cost the city will pay to develop a drainage system. If detention is provided, no fee is assessed.
Boulder, Colorado	Monthly drainage fee that is assessed against all property in the city on the basis of surface area and runoff coefficient. Efforts to retain runoff onsite will result in lower monthly charges.
Metropolitan Sanitary District of Greater Chicago	Requires provision for stormwater retention before granting sewer connection permits to new developments. The maximum release rate is computed by the Rational Formula with a 3 year rain and a coefficient of 0.15. Storage must be designed for the 100 year storm.
Montgomery County, Maryland	The State of Maryland has classified sediment as a pollutant under its Water Pollution Control Act and Montgomery County's program is an example of the result. The recommendations of the SCS on erosion control must be met to obtain clearing and grading permits in the county. Detention ponds are part of the requirements for approval.
Fairfax County, Virginia	The county has a history of runoff control similar to that of Montgomery County. Erosion and sediment control has been mandated during construction since the late 1960s. Temporary detention ponds were used at most sites and permanent detention must be evaluated for all new developers.
Springfield, Illinois	Sewer ordinance for combined sewer areas that has decreased runoff by a successful campaign to disconnect sewer downspouts from the sewer system.

in. x 2.54 = cm
acre x 0.405 = ha

Model Ordinance Outline

A model ordinance has been developed in reference [32]. The following outline covers many of the recommended points.

1. Scope. The ordinance is referenced to existing legislation to prevent overlap or conflict.
2. Definitions. Engineering terms and concepts used in the ordinance should be clarified.
3. Objectives. This section is used to give direction to ordinance and to help the citizenry and courts understand the purposes of the law. Several objectives were listed earlier.
4. Floodplain Regulation. Develop regulations for land use within the contours of the 100 year flood.
5. Hydrologic and Hydraulic Studies. Developers should submit runoff studies for a proposed project. The reports would contain details of existing and projected runoff volumes and rates to serve as a basis for designing detention facilities and measuring potential impacts on downstream systems.
6. Improvements Required. Depending on the objectives of the ordinance, improvements may be required to meet runoff standards. Detention facilities could be required and a maximum release rate specified. This is the most important part of the ordinance as it is where the chosen methodology is developed.

SUMMARY

Nonstructural and low structurally intensive alternatives, termed best management practices (BMPs), offer considerable promise as the first line of action to control urban runoff pollution. By treating the problem at its source, or through appropriate legislation curtailing its opportunity to develop, multiple benefits can be derived. These include lower cost, earlier results, and an improved and cleaner neighborhood environment.

The greatest difficulty faced by BMPs is that the action-impact relationship are almost totally unquantified. It is clear that onsite storage, for example, can be closely related to reduced downstream conduit requirements but the net water quality benefits are far less defined. Similarly, cleaner streets and neighborhoods and enforced legislation will eradicate gross pollution sources but to what limit should they be applied and who will bear the cost? The final answers of cost effectiveness will not be found short of trial implementation. Key demonstration projects in this regard, both in the early planning stages, are expected to be implemented in Bellevue, Washington (4 years), and Orlando, Florida (2 years) [33].

The alternatives, or preferably supplements to BMP, are discussed in the next section.

SECTION 7

UNIT PROCESSES

Many treatment alternatives are available to planners and designers to control stormwater pollution; they have been demonstrated either on an individual basis or as dual use facilities in conjunction with dry-weather treatment facilities. The stormwater treatment alternatives presented in this section include storage, physical treatment, biological treatment, land treatment, and disinfection. The alternatives are discussed on a unit process basis; however, individual processes or combinations of processes may be implemented on various scales to produce the required degree of treatment.

It has been concluded that some form of storage or flow equalization must be considered in implementing these stormwater treatment options to reduce, in size, number, and costs, the treatment facilities required [1].

Actual operational data for most demonstration and prototype stormwater facilities are limited, but it is emphasized that the receiving water condition and/or degree of receiving water improvement be evaluated on a cost-effectiveness approach. Models and modeling techniques have been instrumental in this regard.

Master planning approaches using storm and combined sewer treatment processes are discussed in Section 8, Applications, for several case history sites.

STORAGE

Because of the high volume and variability associated with storm and combined sewer overflows, storage is considered a necessary control alternative. Storage facilities are frequently used to attenuate peak flows associated with these discharges, reducing in magnitude and size of facilities required for further treatment. Storage, however, with the resulting sedimentation that occurs due to increased detention times, can also be considered a treatment process. Many such facilities are designed to operate as sedimentation basins as well as storage tanks for flows that exceed the storage capacity. Characteristics of sedimentation systems are described under Physical Treatment Alternatives.

Storage facilities may be analyzed and designed by various rational methods [2], however, recent studies offer a cost-effectiveness approach for sizing storage facilities coupled with secondary treatment for various pollutant removal constraints [3, 4]. This approach provides a first-cut methodology for comparing alternative costs at different levels of treatment for different combinations of storage treatment processes.

The two types of storage facilities discussed include inline and offline storage. Source ponding and rate control were discussed previously in Section 6.

Inline Storage

Inline storage, the use of the unused volume in interceptors and trunk sewers to store runoff, is a particularly attractive option for controlling urban runoff. This alternative includes installation of effective regulators, level sensors, tide gates, rain gage networks, sewage and receiving water quality monitors, overflow detectors, and flowmeters and then applies computerized collection system control. Such systems have been developed and successfully implemented in Seattle, Minneapolis-St. Paul, and Detroit [2, 5-7].

The basic elements of a monitoring and control system may include all or combinations of the following: (1) remote sensors (rain gages, flow level and selected quality monitors--such as DO, TOC, SS, and/or pH probes, gate limit switches and position monitors); (2) signal transmission (leased telephone wires, pneumatic circuits); (3) display and logging (central computer, graphic panels, warning lights); (4) centralized control capability (control of system gates and/or pumps from a central location); and (5) in the case of fully automated control, a computer program that makes decisions and executes control options based on current monitoring data and memory instructions.

Descriptions of regulators commonly found in combined sewer systems along with installed construction and annual costs are found in the literature [2].

Inline Storage Effectiveness--

Several prototype inline storage facilities are currently in operation, showing satisfactory effectiveness in reducing total overflow volume and the number of overflow events. It has also been shown that as operators become more familiar with the system, the effectiveness of the system operation increases.

The Seattle computer controlled inline storage system, with an estimated maximum safe storage capacity of 67.5 ML (17.8 Mgal) in the trunklines and interceptors, has evolved through several control modes and is now operating under automatic control. The increased storage effectiveness as a result of increasing system control is shown in Figure 28 [5]. The regression lines represent data from 762 separate recorded overflow events from 341 out of 514 storm events during the 3-1/2 year demonstration period.

The Detroit Metro Water Department (DMWD) sewer monitoring and remote control system with an estimated 530 ML (140 Mgal) of controlled inline storage and an additional 568 ML (150 Mgal) of uncontrolled storage (storage that is not a result of the control system), operates in the supervisory control mode [7]. The system captured a total volume of wastewater amounting to 21 575 ML (5.7 billion gal) during the 18 month demonstration period. An estimated 3.2 million kg (7 million lb) of BOD and 5.9 million kg (13 million lb) of suspended solids were prevented from entering the Rouge and Detroit rivers. During the first 6 months of operation, the DMWD was able to completely

contain an equivalent uniform depth of rainfall of 0.18 cm (0.07 in.) over Detroit's 363 km² (140 mi²) area. Through operator experience and knowledge of the interceptor system, this was increased to 0.36 cm (0.14 in.) during the last 6 months of the demonstration period.

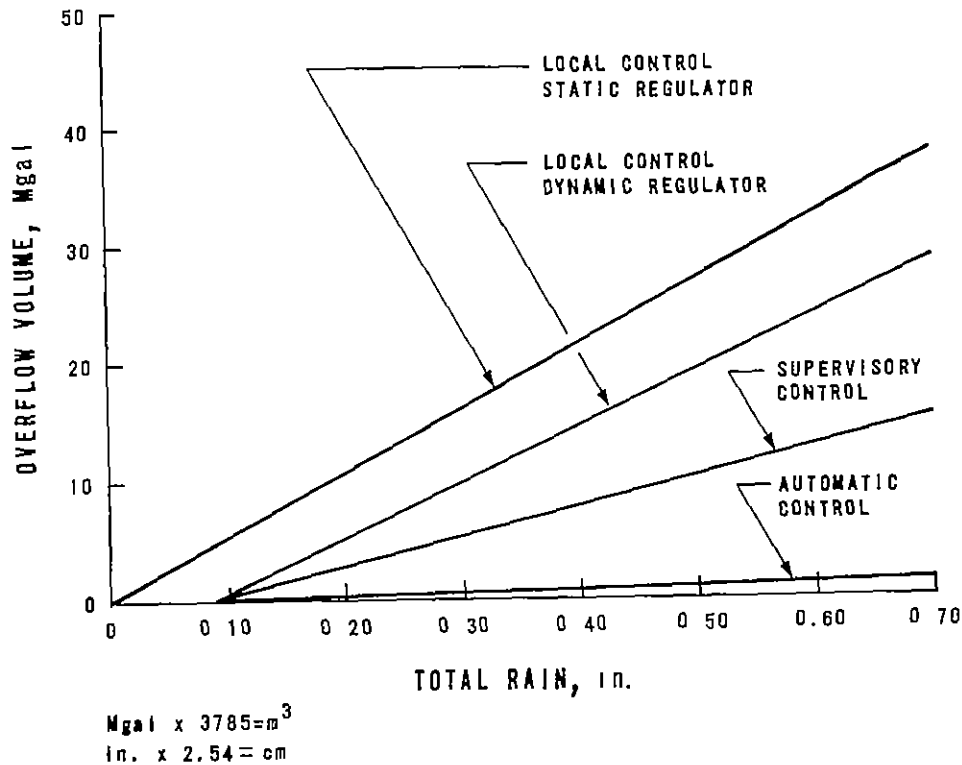


Figure 28. Inline storage effectiveness regression lines for each mode of control.

System Evaluation--

Management effectiveness of inline storage systems may be increased through equipment and hardware selection, implementation, early warning systems, and knowledge of the type of storm to be expected.

Seasonal storm patterns and types in Seattle have been identified as to their effect on the storage system [5]. The control system is used most often during the winter rainy season in which long duration rainfall events with moderate intensities are common. Heaviest loads are put on the computer system with these storms when interceptors are full or nearly full due to the long duration with areawide involvement.

Advanced warning systems have been credited for improved performance of inline storage systems. Surveillance and early attention to potential mechanical and control problems, early action and preparation for storm events, and logical use of all available system storage have contributed to Seattle's computerized system's success [5]. Radar displays of approaching storms gives Detroit

system operators advanced warning of approaching storms and facilities pumpdown procedures to maximize storage capacity in the system [7].

Increased density of rain gages, level sensors, and overflow status monitors are recommended for increased system sensitivity. This is especially true when utilizing systems with limited storage capacity. Standardization of data collection, display, and computer hardware and software is recommended to prevent potential programming and interfacing problems and would greatly reduce costs [5-7].

Inline storage systems are also applicable for use during dry weather. System monitoring has enabled the DMWD to suspend pumping at the wastewater treatment plant for periods of up to 6 hours to perform maintenance and modifications without causing combined sewer overflows. In addition, monitoring has enabled DMWD to hold back flow from portions of the system to allow for sewer inspection and maintenance [7].

Recent literature has developed criteria, rationale, and guidelines for planners, managers, and designers concerning implementation of automation and control facilities for combined sewer systems [8-10].

Operational Problems--

Operational problems associated with inline storage control systems include computer programming and hardware design, and control equipment implementation.

To develop a functional computer control system, the following sequence of system design has been demonstrated to prevent reprogramming and redesign of the system [5].

1. Preparation of overall system design
2. Preparation of system programs
3. Preparation of applications programs

A system of debugging foreground programs on-line should also be provided. When system problems are encountered the following sequence of sources have been recommended:

1. Program bugs
2. Inadequate hardware documentation
3. Hardware malfunction
4. Hardware design deficiencies

Electrical noise has been the cause of many problems encountered in computer monitoring and control systems with telemetry or data transmission [5, 7].

This causes a loss of accuracy in the data requirements needed for system control.

Requirements for dependable service from control system equipment is paramount to efficient operation. Studies in Detroit show that although hydraulic operated regulators may be more maintenance free and faster acting, they may not provide the degree of safety to warrant their use. Hydraulic operators may tend to drift from their set position causing unwanted overflows, and are difficult to operate manually in case of failure. Electrically operated gates once positioned will not drift and can be manually overridden during power failure [7].

Costs of Inline Storage Systems--

Costs associated with inline storage systems are summarized in Table 70. Costs include regulator stations, central monitoring and control systems, and miscellaneous hardware.

TABLE 70. SUMMARY OF INLINE STORAGE COSTS^a

Location	Storage capacity, Mgal	Drainage area, acres	Capital cost, \$	Storage cost, \$/gal	Cost per acre, \$/acre	Annual operation and maintenance \$/yr
Seattle, Washington [2, 5]						
Control and monitoring system	....	.....	3 500 000	....	...	73 000
Automated regulator stations	...	.....	3 900 000	....	...	219 200
	17.8	13 120	7 400 000	0.42	564	292 200
Minneapolis-St. Paul, Minnesota [2, 6]	NA	64 000	3 000 000	....	47	.....
Detroit, Michigan [7]	140	89 600	2 810 000	0.02	31	.....

NA = not available.

a. ENR 2000.

\$/acre x 2.47 = \$/ha

\$/gal x 0.264 = \$/L

Mgal x 3 785 = m³

Offline Storage

Offline storage is used to attenuate storm flow peaks, reduce storm overflows, and capture the first flush, or provide treatment in the form of sedimentation when storage capacity is exceeded. Offline storage facilities may be located at overflow points or near dry-weather or wet-weather treatment facilities, depending on the type and function of the storage facility to be used. Offline storage may also be used for onsite storage of runoff, as described in Section 6.

Types of Offline Storage--

Offline storage facilities have been designed for flow containment to reduce in magnitude the peak flow entering downstream dry- or wet-weather treatment facilities, and for treatment by detention and sedimentation of stormwater before discharge to receiving waters. Simplified schematics of these operations are shown in Figures 29 and 30. Offline storage facilities used for sedimentation are discussed under Physical Treatment Alternatives.

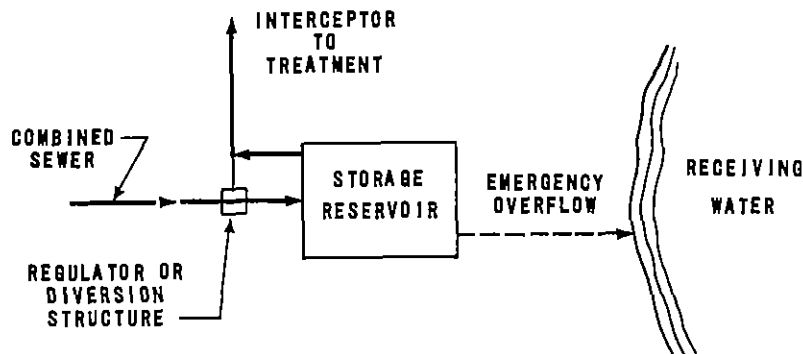


Figure 29. Flow schematic of storage used for containment.

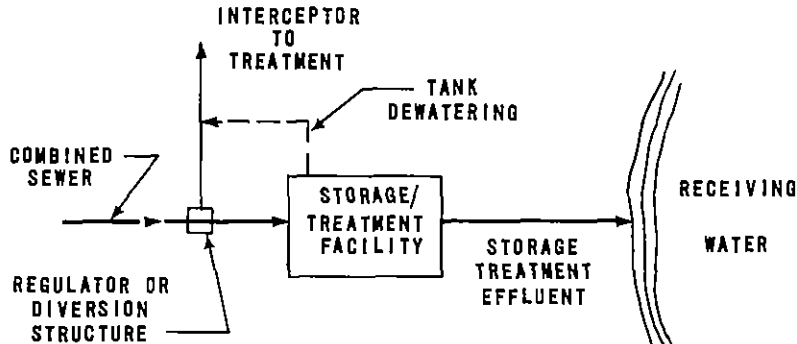


Figure 30. Flow schematic of storage/treatment facility.

Flow Containment--Flow containment facilities are usually constructed of earthen lagoons, reservoirs, or lined basins in low population density areas, less than 25 persons per hectare (10 persons per acre), where land costs are lower and availability is higher [3]. Storage facilities of this type usually contain in excess of 50% of the potential overflow volume per year.

Storage/Detention--Storage/detention facilities provide containment for small overflows and provide detention and thus primary treatment for overflows that exceed the storage capacity. They are usually characterized by covered concrete tanks, providing less than 50% overflow volume reduction and are

constructed in high density areas, greater than 25 persons per hectare (10 persons per acre) because of land costs and land availability [2, 3].

Storage System Characteristics--

Basic appurtenances common to storage facilities include flow diversion or regulation structures, coarse screening, storage overflow structures, and dewatering by pumping or gravity. In addition, storage/detention facilities which provide primary treatment may include all or combinations of the following:

- Fine screening of the influent
- Disinfection systems
- Fine screening or other treatment of the effluent
- Sludge/solids collection and removal

Sludge/solids collection and removal is perhaps one of the most important operations in the storage operation, as inadequate removal can generate volatile gas and cause mechanical malfunctions and odors. Typical collection equipment includes traveling bridge sludge scrapers and hydraulic dredges [2, 11, 12]; mechanical mixers, recirculation pumps, and compressed air for solids resuspension and removal [13-15]; automatic and manual flushing [16, 17]; and use of street sweepers in lined basins [18]. Use of automatic and mechanized methods of solids removal was shown to be more effective than manual washdown operations [12].

Design Criteria--

Storage facilities have been designed using concepts based on duration-frequency analysis of local rainfall events [2]. Storage selection and sizing should also incorporate receiving water conditions as part of the design criteria. Evaluation of the percent reduction of pollutants required to obtain the most cost-effective design must also be compatible with water quality goals.

Studies for Milwaukee have developed process curves for detention tanks, evaluating pollutant reduction and volumetric efficiency for several tank volumes. Suspended solids and BOD retention and percent of storm volume retained for both wet and dry year rainfalls are shown in Figure 31 [13]. The study also showed a decreasing efficiency per unit volume as tank size increases, as shown in Figure 32.

Offline Storage Effectiveness and Applications--

Offline storage facilities have demonstrated their effectiveness in controlling storm and combined sewer overflows. Many regional plans include storage or combinations of storage alternatives as an integral part of the overall control process.

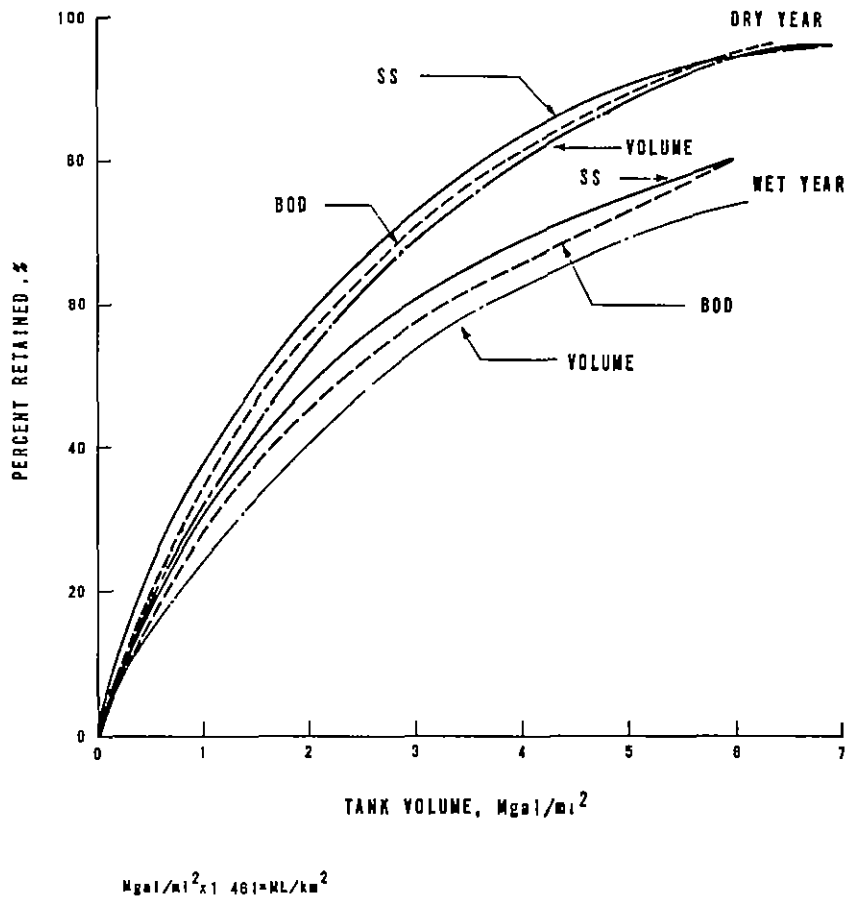


Figure 31. Pollution and volumetric retention versus storage tank volume for wet- and dry-years.

Characteristics and operational performance of the offline storage facilities are described in the literature [2] and are summarized in Table 71.

Offline storage facilities may also be used to relieve dry-weather treatment plants and pumping stations during plant shutdown, by providing auxiliary storage or treatment and preventing flooding of sewers and overflows of raw sewage. The Spring Creek storage facility, during the 2 year period January 1974 to January 1976, received approximately 19 dry-weather flow events as a result of treatment plant shutdowns and malfunctions.

Because of the success of Boston's Cottage Farm Chlorination and Detention Station [2, 17], the Charles River Marginal Conduit Project is currently under design and construction [19, 20]. The purpose of the facility is to avoid pollution between the existing and the proposed dams on the Charles River and to improve water quality for recreational purposes.

The facilities are designed to treat the 1 in 5 year storm flow of 14 150 ML/s (323 Mgal/d), representing an estimated rainfall intensity of 1.19 cm/h (0.47 in./h).

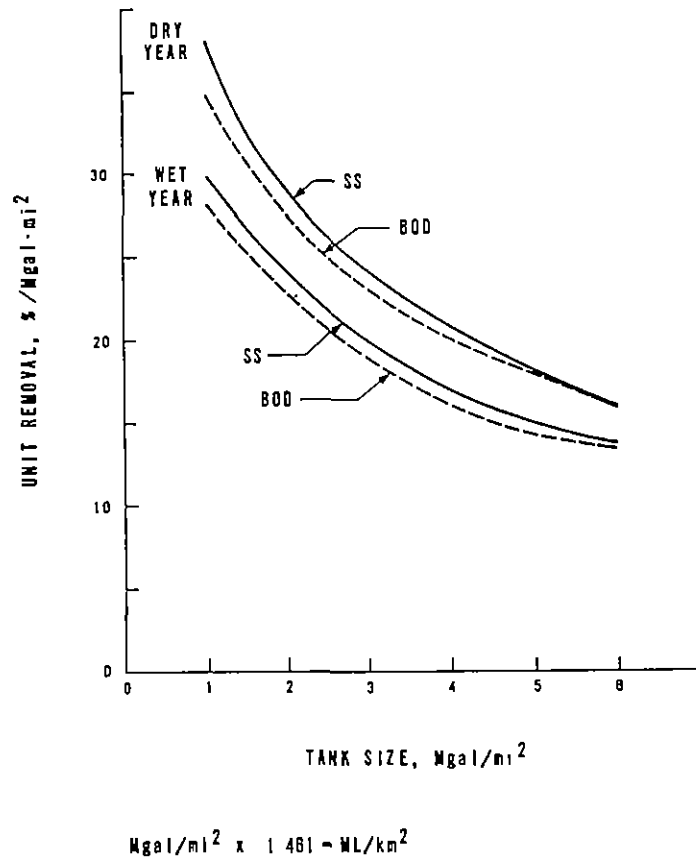


Figure 32. Unit removal efficiencies for combined sewer overflow detention tanks.

The pollution control facilities include:

- Interceptor sewer system, which collects combined sewer overflow to prevent discharge to the Charles River
- Detention and chlorination facilities with effluent pumping station
- Outfall force main to a point below the proposed Charles River Dam

The detention and chlorination facilities will include prescreening, six covered concrete tanks with a total storage capacity of 4.54 ML (1.2 Mgal), and chlorination facilities. System components and operation are similar to Cottage Farm Detention and Chlorination Station.

Characteristic operational parameters for the treatment system are summarized below:

- Frequency of activation approximately 55 times/year or about 4.5 times/month

TABLE 71. DESCRIPTION OF OFFLINE COMBINED SEWER OVERFLOW STORAGE FACILITIES

Location	Description of facilities	System operation	Comments
Akron, Ohio [21]	The underground void space storage tank facilities include a diversion manhole, a 0.38 ML (0.1 Mgal) clarifier, a 3.8 ML (1 Mgal) plastic lined storage basin filled with inert aggregate, an overflow channel to the receiving water, and chlorination facilities. The clarifier chamber contains a tube settler.	Flow is diverted to the clarifier when interceptor capacity is exceeded. As the outlet capacity from the clarifier is exceeded, the flow backs up and overflows to the storage basin. Overflow from the storage basin is discharged to the receiving water. The facilities are dewatered by gravity as interceptor capacity becomes available.	The void space storage concept was used for beneficial land use above the storage basin. Tube settlers do not work effectively in this application. High solids loading to the exposed media of the storage basin may drastically reduce infiltration rates into the bed. Operational since 1974.
Milwaukee, Wisconsin [13] Humboldt Avenue detention facilities	The facilities include a 14.8 ML (3.9 Mgal) covered concrete storage tank, a mechanically cleaned bar screen, a dewatering pumping station, and chlorination facilities. Solids settled in the tank are resuspended by mechanical mixers prior to dewatering.	The tank serves as a settling basin for combined sewer overflow from large storms and totally contains those of smaller storms. Reduction in volume of 67%, suspended solids of 70%, and BOD of 67% were reported for overflow entering the receiving waters.	Effects of a "first flush" condition are evident in this system. Operational since 1969.
Boston, Massachusetts [17] Cottage Farm detention and chlorination station	The detention and chlorination facilities include a 0.38 ML (0.1 Mgal) wet well, and 6 parallel covered concrete storage basins totaling 4.54 ML (1.2 Mgal). The facilities also include prescreening, chlorination, and fine screening of the effluent.	The influent channel is designed to permit sequential filling of the basins as capacity is needed. Reduction in volume of 14%, suspended solids of 45%, and BOD of 42% were reported for overflows entering the Charles River. Small storms that are totally contained and the contents of the basins after large storms are returned to the interceptor for treatment.	The main purpose of this facility is treatment by sedimentation during large overflow events as indicated by the percent volume reduction. Operational since 1971.
New York City, New York [22, 23, 24, 25] Spring Creek	Spring Creek has 6 covered concrete retention basins with a total capacity of 46.9 ML (12.4 Mgal). An additional 49.2 ML (13 Mgal) of storage was estimated to exist in the trunk sewer. The facilities include mechanically cleaned bar racks, chlorination, centrifugal grit separators, and traveling bridge hydraulic sludge washdown devices.	The retention basins provide removal of settleable solids and floatables from overflows, together with disinfection. The system was designed to contain 50% of the summer storms; however, due to the large storage capacity in the trunk sewer, 80 to 85% of the summer storms are contained. Removals from the overflow from storage to the receiving water are: suspended solids, 40%; BOD, 30%; settleable solids, 92%.	Potential overflow is estimated to occur with 0.81 cm (0.32 in.) of rainfall. No estimate of percent volume, suspended solids, and BOD (mass basis) reduction to the receiving water is available. Operational since 1972.

TABLE 71. (Continued)

Location	Description of facilities	System operation	Comments
Chippewa Falls, Wisconsin [18]	The open storage facilities include a diversion structure, bar screen, pumping station, 10.7 ML (2.8 Mgal) open asphalt-lined storage basin, and a pond overflow structure. Solids removal is facilitated by mechanical street sweepers.	The primary function of the facilities is to store potential overflows, returning them to the interceptor as treatment capacity becomes available. Volume reduction was 93.7%, 95% of the suspended solids and 98.2% of the BOD were prevented from entering the Chippewa River.	The dry-weather treatment plants secondary clarifiers were increased in size to retain solids as a result of the increased flow from storage. No detrimental effects on the activated sludge process have been noted as a result of the storage facility. Operational since 1969.
Chicago, Illinois [2, 11, 26]	The deep tunnel project includes tunnels for transmission and storage, mined quarries for additional storage and treatment by sedimentation, and improvements to dry-weather treatment plants to handle the increased wet-weather flow. The tunnel system includes 201 km (125 miles) of deep rock tunnels with an estimated storage capacity of 11 350 ML (2 998 Mgal), and vertical drop shaft entrance structures. Quarry storage is estimated at 156 400 ML (41 315 Mgal). The quarry system includes mechanical aeration, hydraulic dredge sludge removal, and pumping.	The first phase tunnels, storage only without reservoirs, are estimated to reduce overflows from 100 to 10 per year. With only the tunnels in operation, the BOD reduction is expected to be 90% and the volume reduction to the river, 75%. Final plans include instream aeration in addition to the tunnels, reservoirs, and treatment plant improvements to meet dissolved oxygen requirements over the entire 129 km (80 miles) of waterways during critical summer conditions.	Presently three segments of the tunnel system are on line. These include (1) Brookfield La Grange, (2) Crawford Avenue, and (3) Lawrence Avenue. The frequency of overflow using this plan is estimated to be 4 times in 21 years.
Sandusky, Ohio [2, 16]	The offshore underwater storage facility includes a leaping weir regulator, bar screen, diversion weir to allow filling of either or both of the tanks, 2 nylon-reinforced synthetic rubber storage tanks, and dewatering pumps. The storage capacity is 1.36 ML (0.36 Mgal), including the added capacity due to fabric elongation.	Overflow from the combined sewer system is diverted to the underwater storage tanks, and after capacity is reached is directed out the safety overflow. The tanks are dewatered back to the interceptor as treatment capacity becomes available. The system retained 50% of the overflow volume and over 90% of the pollution load. Overflow from the facility occurred approximately 1% of the time.	Operational problems encountered with some of the support equipment included: backflow valves, pressure relief valves, and the tank level control system. Accumulation of silt also created operational problems. Pilot facility operational period was from 1968 to 1969.

TABLE 71. (Concluded)

Location	Description of facilities	System operation	Comments
Washington, D.C. [2, 15]	Combined sewer overflow is stored in 2 underwater nylon reinforced synthetic rubber storage tanks. The storage volume is 0.76 ML (0.2 Mgal). The facilities also include grit chambers, bar screen, comminutor, and return pumping plus instrumentation.	The facilities were designed to contain a portion of the first flush from the combined sewer system. Stored stormwater and solids are pumped to an interceptor after storm flows subside. Approximately 6.06 ML (1.6 Mgal) of overflow has been diverted to storage from 38 storm events.	Operational problems included bag anchoring and tearing, air release devices, and general equipment malfunctions. Compressed air was injected into the storage bags to agitate settled solids for pumping to the interceptor. Operational period January through September 1969.
Columbus, Ohio [3, 12] Whittier Street	Three open concrete storm standby tanks with a total volume of 14.2 ML (3.75 Mgal) were constructed in 1932 with modifications made in 1967. The facilities include traveling bridge sludge scrapers, sludge removal pumps, and regulator structures and gates.	The main processes are pollutant removal by containment and sedimentation. A rainfall of about 0.51 cm (0.2 in.) over the drainage area will put the tank in operation. After storm flows subside, the contained volume and solids are pumped back to the interceptor for further treatment.	Pollutant removal rates due to sedimentation are discussed in the next section. The facilities are operational in present mode since 1967.
Cambridge, Maryland [14]	This underwater storage facility consists of flow metering, bar screen, diversion manholes, a pumping station, and a 0.94 ML (0.248 Mgal) underwater steel storage tank with a flexible rubber diaphragm.	The capacity of the facility is sufficient to totally contain 40 of the 55 storms per year and about 96% of the total annual overflow volume. The facility will capture an estimated 3 240 kg (7 136 lb) of the 3 370 kg (7 435 lb) of BOD in the combined sewer overflow, or about a 96% reduction.	Due to unfavorable public acceptance, the pilot plant facility was removed from the site before completing a satisfactory evaluation. Site selection was proved to be a critical design factor to prevent public disturbance, and includes land use, tidal conditions, and the type of storms to be captured.

- Maximum 1 year return period overflow rate = 5740 L/s (131 Mgal/d)
- Estimated average overflow duration = 7 h
- Estimated maximum overflow duration = 20 h
- Chlorine contact time at design flow = 7.3 min

Projected pollutant removal and operational performance of the Charles River facility are presented in Table 72 [19]. Overall removals expected are: BOD, 61%; suspended solids, 51%; and settleable solids, 61%.

TABLE 72. PROJECTED PERFORMANCE OF CHARLES RIVER MARGINAL CONDUIT STATION [19]

Flows to station			Detention time, min	Reduction, % ^a		
Mgal/db	h/yr	Mgal/yr		BOD	Suspended solids	Settleable solids
1 0	5 260	223	....	100	100	100
2.0	2 450	206	.....	100	100	100
3 0	550	69	.....	100	100	100
4 0	100	17	.....	100	100	100
5.0	50	11	342.6	88	98	99
15.4	160	103	111.2	40	56	83
17.5	20	15	97.8	36	54	77
25.5	35	37	67.1	28	34	57
37 5	35	55	45.7	24	29	45
50 5	20	42	33.9	20	24	35
65.5	15	41	26.1	17	19	28
81.0	10	34	21.1	15	17	24
98.0	5	21	17.5	14	16	21
131	15	83	13.1	12	15	16
164	5	34	10.4	10	11	14
198	3	25	8.6	8	9	12
230	7	68	7.4	6	7	10
263	3	33	6.5	5	6	8
298	2	25	5.7	3	5	6
323	3	41	5.3	2	4	5
323	12	..	....	...	...	...
Total	8 760	1 183				

a. Treatment also includes disinfection of all overflows.

b. Flows less than or equal to 4 Mgal/d are assumed totally contained and pumped to Charlestown interceptor to dry-weather treatment. Dry-weather facilities are assumed 100% efficient in these performance estimates.

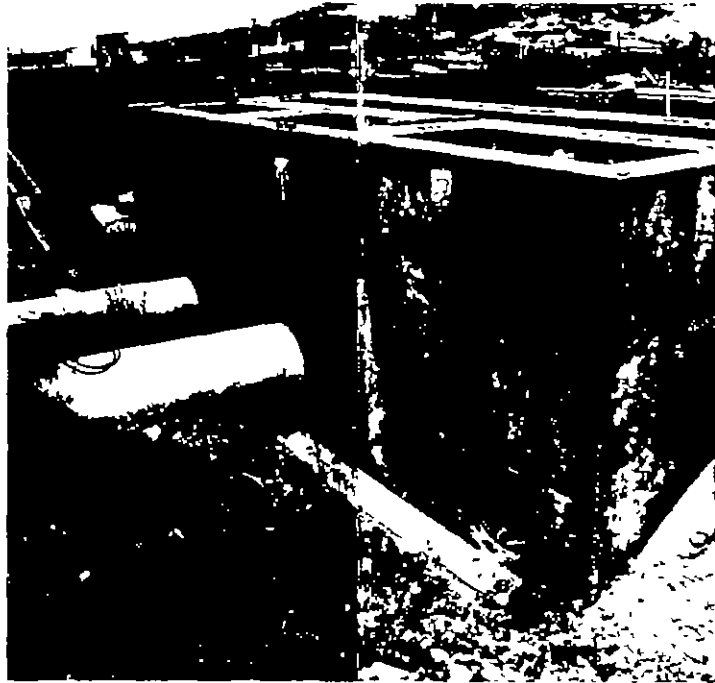
Mgal/d x 43.808 = L/s

Mgal x 3.785 = ML

An implementation of offline storage was recently constructed in Rohnert Park, California. These facilities will store flows greater than 0.18 m³/s (4 Mgal/d) from heavily infiltrated sanitary sewers. As capacity at the regional plant becomes available, the storage facilities will be drained. The facilities, under construction, are shown in Figure 33.



(a)



(b)



(c)

Figure 33. Offline storage facilities, Rohnert Park, California
 (a) Flow regulator/diversion chamber. (b) Splitter box to storage basins.
 (c) Storage basin under construction.

Costs of Offline Storage Facilities--

Updated costs of storage facilities and operation and maintenance costs are presented in Table 73.

Construction cost curves for concrete and earthen storage reservoirs have been developed and are shown in Figure 34 [27]. Earthen reservoir costs include earthwork, liner, paving, seeding, fencing, miscellaneous items, and contingency at 15%. Costs for concrete tanks include concrete and forms, steel, labor, miscellaneous items, and contingency.

PHYSICAL TREATMENT ALTERNATIVES

Physical treatment alternatives are primarily applied for suspended solids removal from wastestreams, and are of particular importance to storm and combined sewer overflow treatment for removal of settleable and suspended solids and floatable material. Physical treatment systems have demonstrated capability to handle high and variable influent concentrations and flowrates and operate independently of other treatment facilities, with the exception of treatment and disposal of the sludge/solids generated from these facilities. The principal disadvantage relates to those periods of time when equipment sits idle during periods of dry weather. When implemented on a dual use basis as either pretreatment or effluent polishing of conventional sanitary sewage treatment plant flows, reduced capital investments may be realized by continuous utilization of the physical treatment system's capacity.

Physical treatment processes that have been demonstrated on either a pilot or prototype scale include: sedimentation and chemical clarification; solids concentration and flow regulation (swirl concentrator/flow regulator); screening; dissolved air flotation; high rate filtration; and a relatively new process, magnetic separation [2, 28]. Many prototype level installations employ combinations of the above unit processes to form integrated treatment systems, or use physical treatment processes in conjunction with biological and disinfection to produce desired water quality goals and pollutant removals.

Process descriptions and installations, process performance comparisons, and operational evaluations of the treatment technologies using recent and past data from new and previous demonstration projects form the base for this report on the state-of-the-art update. Design manuals, procedures, and criteria developed in the literature will be used and demonstrated in the illustrative problem sets [2, 29-32].

Chemical treatment operations are included under physical treatment because physical treatment is an integral part of the overall process. Evaluation of chemical additives such as polyelectrolytes, which enhance physical removals are also addressed.

TABLE 73. SUMMARY OF OFFLINE STORAGE COSTS^a

Location	Storage capacity, Mgal	Drainage area, acres	Capital cost, \$	Storage cost, \$/gal	Cost per acre, \$/acre	Annual operation and maintenance cost, \$/yr
Akron, Ohio [21]	1.1	188.5	455 700	0.41	2 420	2 900
Milwaukee, Wisconsin [13]						
Humboldt Avenue	3.9	570	1 774 000	0.45	3 110	51 100
Boston, Massachusetts						
Cottage Farm Detention and Chlorination Station [17] ^b	1.3	15 600	6 495 000	5.00	416	80 000
Charles River Marginal Conduit Project [19]	1.2	3 000	9 488 000	7.91	3 160	97 600
New York City, New York [22, 23, 25]						
Spring Creek Auxiliary Water Pollution Control Plant						
Storage	12.39	3 260	11 936 000	0.96	3 660	100 200
Sewer	13.00	3 260	11 936 000	0.47	3 660	100 200
	<u>25.39</u>	<u>3 260</u>	<u>11 936 000</u>	<u>0.47</u>	<u>3 660</u>	<u>100 200</u>
Chippewa Falls, Wisconsin [18]						
Storage Treatment	2.82	90	744 000	0.26	8 270	2 700
	<u>2.82</u>	<u>90</u>	<u>744 000</u>	<u>0.26</u>	<u>8 270</u>	<u>2 700</u>
Chicago, Illinois [2, 11, 26]						
Tunnels and pumping	2,998	240 000	870 000 000	0.29	3 630	.. .. .
Reservoirs	<u>41 315</u>	<u>.....</u>	<u>682 000 000</u>	<u>0.02</u>	<u>2 840</u>	<u>.....</u>
Total storage	44 313	240 000	1 552 000 000	0.04	6 470	.. .. .
Treatment	<u>.....</u>	<u>.....</u>	<u>1 001 000 000</u>	<u>.....</u>	<u>4 170</u>	<u>.....</u>
	<u>44 313</u>	<u>240 000</u>	<u>2 553 000 000</u>	<u>0.04</u>	<u>10 640</u>	<u>8 700 000</u>
Sandusky, Ohio [16]	0.36	14.86	520 000	1.44	35 000	6 200
Washington, D.C. [2, 15]	0.20	30.0	883 000	4.41	29 430	3 340
Columbus, Ohio [2, 3, 12]						
Whittier Street	3.75	29 250 ^c	6 144 000	1.64	210	.... ..
Cambridge, Maryland [14]	0.25	20	320 000	1.28	16 000	14 400

a. ENR 2000.

b. Estimated values, facilities under design and construction.

c. Estimated area.

S/acre x 2.47 = \$/ha

S/gal x 0.264 = \$/L

Mgal x 3785 = m³

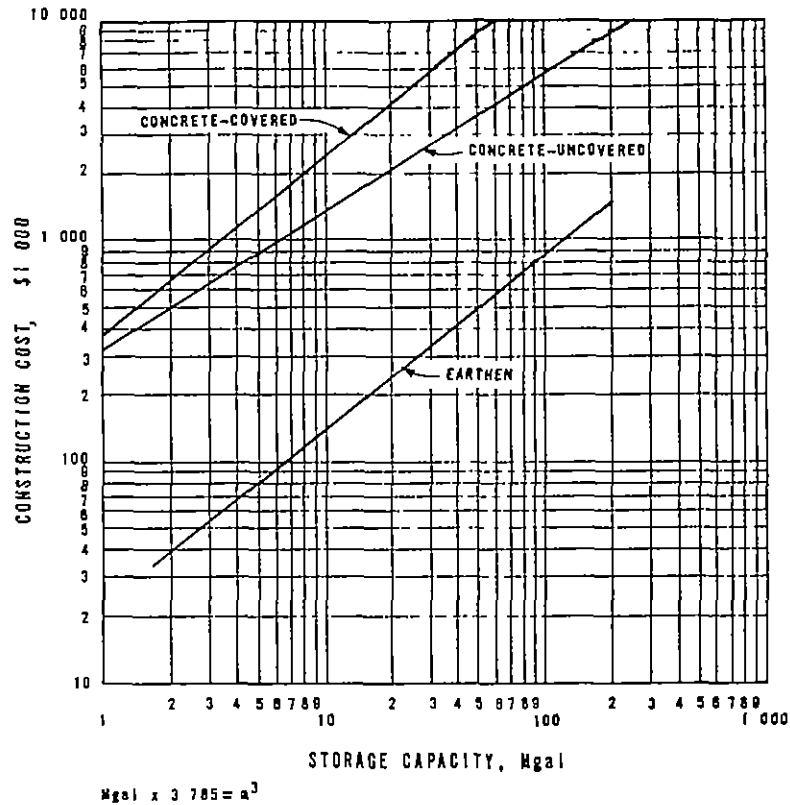


Figure 34. Storage reservoir construction costs (ENR 2000).

Process Description and Facilities Installations

Process descriptions and typical physical treatment installation case histories have been developed [2]. These and several new concepts for treating storm and combined sewer overflows are summarized in the following.

Sedimentation--

Many of the storage installations described in the preceding section also double as primary sedimentation facilities for flows that exceed storage capacity. For several installations, sedimentation is the main treatment process where the total volume captured in storage is less than 50% [12, 13, 17, 19, 22, 33]. Sedimentation has also been used for pretreatment and post-treatment in addition to storage [21, 33]. Most sedimentation/storage facilities also include the following or combinations of the following in the complete treatment system:

- Prescreening
- Postscreening
- Removal of floatables
- Disinfection

Significant sedimentation demonstration and prototype projects are summarized in Table 74.

TABLE 74. SUMMARY OF TYPICAL SEDIMENTATION FACILITIES^a

Project location	Type of sedimentation facility	Volume of sedimentation tank, Mgal	Maximum design flowrate, Mgal/d	Period of operation
Akron, Ohio [21]	Tube settlers in clarifier and void space storage basin	0.1	149	1974 to present
Boston, Massachusetts				
Cottage Farm Detention and Chlorination Station [17]	Covered concrete tanks	1.3	233	1971 to present
Charles River Marginal Conduit Project [19, 20]	Covered concrete tanks	1.2	323	Under design and construction
Columbus, Ohio [2, 12]				
Whittier Street	Open concrete tanks	3.75	403	1932 to present; modified in 1966
Dallas, Texas [33]				
Bachman Stormwater Plant	Open concrete tanks and tube settlers with waste lime and polymer addition	1.2	28	1971 to present
Milwaukee, Wisconsin				
Humboldt Avenue [13]	Covered concrete tank	3.9	246	1969 to present
New York City, New York				
Spring Creek [2, 22, 25]	Covered concrete tanks	12.4	2900	1972 to present
Saginaw, Michigan [34]				
Weiss Street	Concrete tanks	3.9	...	In design
Hancock Street	Covered concrete tanks	3.5	323	Under construction, 90% complete

a. Treatment of combined sewer overflows except Dallas facility which treats excessive sanitary flows caused by infiltration.

Mgal/ x 3785 = m³

Mgal/d x 43.808 = L/s

Swirl and Helical Concentrator/Regulators--

Solids concentrator/regulators achieve both quantity and quality control of wastestreams laden with suspended material. The two principal types of control devices developed include the swirl and the helical bend concentrator/regulators [2, 29, 30]. The principal mechanism for dynamic solid/liquid separation is secondary fluid motion attained through long path geometric flow patterns [29].

Helical bend concentrator/regulators have been modeled and design criteria and comparative cost evaluations have been developed [30]. Although no demonstration projects have been implemented in the United States, helical bends appear more practical as inline devices rather than as satellite or offline devices. Swirl concentrators have been modeled and, in several cases, demonstrated for various processes including treatment and flow regulation, grit removal, primary treatment, and erosion control.

- Swirl concentrator/flow regulator--In this application the swirl is used to replace conventional regulators while simultaneously treating combined wastewater by swirl action. During dry weather, sanitary flows are diverted through a channel in the chamber floor into a bottom orifice and discharged to the intercepting sewer. Pumping of the dry-weather flow may be required by limiting hydraulic gradients [35].
- Swirl degritter--The swirl principle has been applied to grit removal for pretreatment prior to other treatment processes and as a degritter for the underflow from a swirl concentrator/regulator [36-38]. Swirl degritters usually have a conical shaped hopper below the circular swirl chamber where the solids accumulate before being discharged.
- Swirl primary separator--The swirl primary separator unit was developed to remove a greater fraction of the suspended solids than the swirl concentrator/regulator does. The configuration of the swirl chamber developed was a conical shaped device with a depth approximately equal to the diameter [36, 39]. The relatively high overflow rates (approximately twice that of conventional sedimentation) used in the swirl design at various levels of suspended solids removal may result in less costly construction and require less space than conventional sedimentation basins.
- Erosion control--A modification of the swirl using a conventional cattle watering tank is being investigated for a portable erosion control device [40]. Erosion and construction site stormwater runoff could be rapidly treated before discharge to the receiving water or retention ponds.

Swirl concentrator and helical bend model studies and demonstration projects are summarized in Table 75 and typical swirl installations are shown in Figure 35.

Screening Alternatives--

Screens have been used to achieve various levels of suspended solids removal contingent with three modes of screening process applications.

- Main treatment - screening is used as the primary treatment process
- Pretreatment - screening is used to remove suspended and coarse solids prior to further treatment to enhance the treatment process or to protect downstream equipment